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ORIGINAL RESEARCH

ASSOCIATION OF ISOMETRIC STRENGTH OF HIP AND KNEE MUSCLES WITH INJURY RISK IN HIGH SCHOOL CROSS COUNTRY RUNNERS

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ABSTRACT

Background: High school cross country runners have a high incidence of overuse injuries, particularly to the knee and shin. As lower extremity strength is modifiable, identification of strength attributes that contribute to anterior knee pain (AKP) and shin injuries may influence prevention and management of these injuries.

Purpose: To determine if a relationship existed between isometric hip abductor, knee extensor and flexor strength and the incidence of AKP and shin injury in high school cross country runners.

Materials/Methods: Sixty-eight high school cross country runners (47 girls, 21 boys) participated in the study. Isometric strength tests of hip abductors, knee extensors and flexors were performed with a handheld dynamometer. Runners were prospectively followed during the 2014 interscholastic cross country season for occurrences of AKP and shin injury. Bivariate logistic regression was used to examine risk relationships between strength values and occurrence of AKP and shin injury.

Results: During the season, three (4.4%) runners experienced AKP and 13 (19.1%) runners incurred a shin injury. Runners in the tertiles indicating weakest hip abductor (chi-square = 6.140; p = 0.046), knee extensor (chi-square = 6.562; p = 0.038), and knee flexor (chi-square = 6.140; p = 0.046) muscle strength had a significantly higher incidence of AKP. Hip and knee muscle strength was not significantly associated with shin injury.

Conclusions: High school cross country runners with weaker hip abductor, knee extensor and flexor muscle strength had a higher incidence of AKP. Increasing hip and knee muscle strength may reduce the likelihood of AKP in high school cross country runners.

Level of Evidence: 2b

Keywords: Lower extremity muscle strength, medial tibial stress syndrome, patellofemoral pain syndrome, running

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INTRODUCTION

Cross country is a popular high school sport in the U.S. as reflected by the growth of over 25% in participation level for high school cross country in the past decade.[1] However, a consequence of the increased participation is the corresponding high rate of injury in cross country, with 29-38.5% of runners expected to experience an injury during an interscholastic cross country season.[2,3] Injuries to the knee (including anterior knee pain [AKP] which refers to any issue at the anterior aspect of the knee and may include bursitis, tendinitis, and patellofemoral pain syndrome [PFPS])[4] and shin are common, together comprising 48% of new injuries and 59% of re-injuries.[3,5]

Evidence on the relationships between lower extremity strength and running-related injuries has focused primarily on recreational runners. In cross-sectional studies of recreational runners, reduced hip abductor and knee extensor strength have been observed in runners with overuse injuries, including PFPS, when compared with asymptomatic runners.[6-8] Females with PFPS displayed hip abductor and extensor weaknesses and increased hip internal rotation motion while running compared with controls.[9] Hip and knee strengthening exercises are commonly used for the treatment of injured runners to address areas of impaired strength and biomechanics associated with injury.[10-14]

Along with their use in rehabilitation, strengthening exercises have been suggested for the prevention of common running injuries.[6,15-19] However, as most studies have used a cross-sectional study design to examine the association between lower extremity muscle weakness and running-related injury, it is unclear whether weakness is a risk factor or occurs secondary to the injury.[17] Presently, there are few prospective investigations that have assessed the role of lower extremity muscle strength impairment as a risk factor for AKP or shin injury risk in adult runners. A study of over 600 novice recreational runners found runners with higher eccentric hip abductor strength had a lower risk of developing PFPS.[20] In contrast, a prospective study of 77 novice female recreational runners noted hip strength values for extensors, flexors, abductors, adductors, external and internal rotators were not associated with the development of patellofemoral dysfunction during a training program.[21]

In a prospective study of 125 collegiate cross country runners, Bennett et al observed that lesser isotonic ankle plantar flexor endurance was not significantly associated with exercise related leg pain.[22] In a prospective investigation of 111 track and field athletes 17-26 years old, females with stress fractures, most frequently of the tibia, were found to have less lean mass in their lower limb and smaller calf girth than female track and field athletes who did not incur a stress fracture.[23,24] Track and field athletes with a one cm decrease in corrected calf girth were also four times more likely to incur stress fracture.[23] Verrelst et al found that decreased hip abductor strength predicted the development of exertional medial tibial pain while running in a prospective study of 95 female collegiate physical education students.[25]

A systematic review on hip strength and PFPS indicated that while many cross sectionally-designed studies reported hip muscle weakness in those with PFPS, few prospective studies have found hip muscle weakness as a significant risk factor.[26] The authors concluded that hip muscle weakness may be the result of knee pain rather than the cause.[26] In contrast, peak isometric strength for knee extensors and flexors in adolescents with patellofemoral pain did not vary from symptom-free adolescents.[27] However, the isometric knee extensor and flexor muscle strength values were based on a general adolescent population, thus were not specific to runners.

The identification of modifiable risk factors may allow implementation of screening and preventative measures for running-related injuries. The value of hip and knee strength screening in adolescent runners is not known as it is unclear whether decreased strength at either the hip or knee are risk factors for or a result of injury.[26] Prospective evidence on the relationship between lower extremity strength and running injury risk in high school runners is limited. In a study of 98 high school cross country and track runners, Finnoff et al reported that runners with lower pre-injury hip external to internal rotator strength ratios were more likely to develop AKP.[28]

As high school runners have a high incidence of knee and shin injury, the purpose of this study was to determine if a relationship existed between isometric hip abductor, knee extensor and flexor strength and the incidence of AKP and shin injury in high school cross

country runners. The authors hypothesized that runners with higher hip and knee strength values would have a significantly lower incidence of AKP and shin injury than runners with lower strength values. A secondary purpose was to explore hip and knee strength values and injury incidence between girls and boys.

METHODS

Subjects and Setting

This study used a prospective cohort design. An a priori power analysis was performed using an alpha value of 0.05, power of 0.80, and 20% incidence values for AKP and shin injury based on seasonal injury incidence of 38.5% and 52% of injuries affecting the knee and shin.[2,3] With a conservative expected estimate of 15% of non-injured runners with low strength, an expected estimate of 30% of injured (shin injury or AKP) runners with low strength, an odds ratio of 3.0 (corresponding relative risk of approximately 2.0), a sample of 121 runners was indicated to show a statistically significant relationship between strength and shin injury or AKP.[29]

Runners from a Northeast Wisconsin high school were invited to participate in this study. To be included in the study, the runner had to be a member of the boys' or girls' cross country teams, not present with signs or symptoms of a current running-related injury, and be cleared for athletic participation. All runners provided informed consent and guardian/parental consent (for runners less than 18 years of age). The study was approved by the Rocky Mountain University of Health Professions Institutional Review Board

Data Collection

Isometric strength tests

A MicroFET II® handheld dynamometer (Hoggan Scientific, LLC, Salt Lake City, UT) was used to collect bilateral peak isometric strength values for: 1) hip abductors, 2) knee extensors (quadriceps), and 3) knee flexors (hamstrings). Prior to testing, the device was calibrated by the manufacturer. Hip abductor strength was measured with the participant in sidelying (Figure 1). The non-test limb was positioned in 30-45˚ of hip flexion and 90˚ of knee flexion.[30] The pelvis was stabilized to the table using a strap and the test hip was in 0˚ of extension and abducted to parallel with the table. Resistance

Figure 1. *Test position for hip abductors*

was placed just proximal to the lateral malleolus on the test limb.[30] Knee extensors were tested with the participant seated at the end of a table with the test knee at 45˚ of flexion (Figure 2).[31] A stabilizing strap was placed around the thighs and table with resistance applied to the anterior aspect of the tibia 5 cm proximal to the ankle joint. Knee flexor testing occurred with the participant in prone and the test knee flexed to 45˚ (Figure 3). A stabilizing strap was placed around the pelvis and table with resistance applied to the posterior aspect of the tibia 5 cm proximal to the ankle joint.

Peak isometric strength values (N) for two separate trials were collected for each muscle group, with the muscle groups tested in the following order: knee

Figure 2. *Test position for knee extensors*

Figure 3. *Test position for knee flexors*

extensors, knee flexors, and hip abductors. The runners were given five seconds between trials and 30 seconds between muscle groups. During each test, the runners were instructed to "take one to two seconds to reach the maximal effort and then maintain this level for three seconds" pushing as hard as they could.[32] The maximum value (N) of the two trials from each muscle group was multiplied by the length of the resistance moment arm (m) and normalized to the participants' body mass (kg).[33] Moment arm length for knee flexors and extensors was from the medial knee joint line to medial malleolus less five cm and moment arm length for the hip abductors was from the anterior superior iliac spine to the medial malleolus less five cm.[30]

Prior to the main study, inter-rater reliability for each isometric strength test was assessed with 10 participants with 30 seconds to reposition the dynamometer between tests. Inter-rater reliability was determined using intraclass correlation coefficient ($ICC_{3,1}$) and standard error of measurement (SEM) for each muscle group: hip abductors ($ICC_{3,1}$, 0.83; SEM, 1.15N / 0.017 Nm/kg), knee extensors ($ICC_{3,1}$, 0.51; SEM, 3.71N / 0.024 Nm/kg) and flexors ($ICC_{3,1}$, 0.76; SEM, 2.60N / 0.017 Nm/kg).

Injury surveillance

Runners were followed during the interscholastic season to identify occurrences of AKP and shin injury. Prior to the season, team coaches and athletic trainers were instructed in the use of the Daily Injury Report[34] to record occurrences and non-occurrences of injury. An injury was defined as a medical problem resulting from athletic participation that required an athlete to be removed from a practice or competitive event or to miss a subsequent practice or competitive event.[2] Runners who were able to return to full, unrestricted participation prior to the end of cross country practice or meet were not considered injured in this study.[2] Coaches and athletic trainers recorded absences or limitations due to injury and also specified the injured body part.[2]

If a runner reported knee or shin pain, a licensed physical therapist or licensed athletic trainer examined the athlete to determine whether criteria for AKP [1) Pain around the anterior aspect of the knee, 2) insidious onset, and 3) no evidence of trauma (e.g., falls, twists)[35]] or shin injury [1) Continuous or intermittent pain in the tibial region, 2) exacerbated with repetitive weight-bearing activity, and 3) localized pain with palpation along the tibia[13,22,36]] were met.

Data Analysis

The incidence of AKP and shin injury was calculated for all runners and by sex. Mean strength values (average of right and left) for hip and knee muscle groups were used for the injury analysis. As applicable, bivariate logistic regression was used to determine univariate odds ratios (ORs) and 95% confidence intervals (CI) for AKP and shin injuries based on strength tertiles (weakest, middle, strongest) for each muscle group tested. The tertile with the strongest strength values was considered the referent (comparison) group. Separate univariate ORs and 95% CIs were also calculated for girl and boy runners to allow for comparison to published papers that reported sex-specific results.[5,37] An alpha level of 0.05 was used to determine statistical significance for all tests. SPSS Version 22.0 (SPSS Inc, Chicago, IL) was used for all statistical analyses.

RESULTS

Of the 154 runners who participated in the 2014 cross country season, 68 (44.2%) high school cross country runners enrolled in and completed the study (47 girls and 21 boys; age = 16.2 ± 1.3 yrs, mass = 59.6 ± 9.0 kg, height = 168.1 ± 8.7 cm) (Table 1). During the season, 4.4% (n=3) experienced AKP and 19.1% (n=13) of the runners experienced a shin injury (Table 2). The percent of AKP occurrence was

Table 1. *Baseline Characteristics (Mean ± SD) of High School Cross-Country Runners*

	Total (n=68)	Girls (n=47)	Boys (n=21)	p-value*
Age (y)	16.2 ± 1.3	16.2 ± 1.3	16.3 ± 1.5	0.82
Height (cm)	168.1 ± 8.7	164.3 ± 6.3	176.5 ± 7.1	0.000
Weight (kg)	59.6 ± 9.0	57.1 ± 7.5	65.0 ± 9.8	0.001
BMI (kg/m^2)	21.0 ± 2.7	21.1 ± 2.1	20.9 ± 3.7	0.81
Muscle strength (Nm/kg)				
Right hip abductors	0.25 ± 0.08	0.25 ± 0.08	0.25 ± 0.07	0.89
Left hip abductors	0.25 ± 0.07	0.26 ± 0.07	0.25 ± 0.08	0.77
Right knee extensors	0.29 ± 0.05	0.28 ± 0.04	0.31 ± 0.06	0.06
Left knee extensors	0.28 ± 0.05	0.28 ± 0.05	0.30 ± 0.05	0.11
Right knee flexors	0.21 ± 0.04	0.20 ± 0.03	0.22 ± 0.06	0.07
Left knee flexors	0.20 ± 0.05	0.20 ± 0.04	0.21 ± 0.06	0.17
§Mean hip abductors	0.25 ± 0.07	0.26 ± 0.07	0.25 ± 0.07	0.83
§Mean knee extensors	0.29 ± 0.05	0.28 ± 0.40	0.30 ± 0.53	0.07
§Mean knee flexors	0.20 ± 0.04	0.20 ± 0.03	0.22 ± 0.06	0.10

BMI, body mass index.
*Two sample t-test of differences of means for boys and girls.
§Average value of Right and Left.

Table 2. *Distribution of Anterior Knee Pain and Shin Injuries by Sex*

	Total (n=68)		Girls (n=47)		Boys (n=21)	
	N	%	N	%	N	%
Injury type						
Anterior Knee Pain	3	4.4	2	4.3	1	4.8
Shin Injury	13	19.1	4	8.5	9	42.9

N= Number of runners with injury.

similar for girl and boy runners. Boy runners had a significantly higher percent of shin injury than girls ($p = 0.003$).

Runners in the weakest tertile for hip abductor ($p = 0.046$), knee extensor ($p = 0.038$), and flexor strength ($p = 0.046$) had a higher incidence of AKP than those in the strongest tertile (Table 3). As all AKP injuries occurred among runners in the tertile with the weakest tertile values, the likelihood of AKP (i.e., odds ratio) could not be appropriately calculated for each muscle group area. Using the strongest tertile as the reference group, hip and knee muscle strength were not significantly associated with shin injury (Table 4). Within gender, a significant association was found between weaker knee extensor strength and increased occurrence of shin injury ($p = 0.01$) in girls, but no association was found between knee extensor strength and shin injury in boys. No other significant gender-specific associations were found between shin injury and knee flexor or hip abductor muscle strength.

Table 3. *Relationships Between Selected Lower Extremity Muscle Group Strength and Anterior Knee Pain (AKP)*

	Total (N=68)				Girls (N=47)				Boys (N=21)			
	N at risk	% injured	OR	(95% CI)	N at risk	% injured	OR	(95% CI)	N at risk	% injured	OR	(95% CI)
Hip Abductor Strength												
T1 (weakest)	23	13.0	NA	NA	14	14.3	NA	NA	9	8.6	NA	NA
T2	22	0.0	NA	NA	16	0.0	NA	NA	6	0.0	NA	NA
T3 (strongest)	23	0.0	1.00	Ref	17	0.0	1.00	Ref	6	0.0	1.00	Ref
Knee Extensor (Quadriceps) Strength												
T1 (weakest)	22	13.6	NA	NA	16	12.5	NA	NA	6	16.7	NA	NA
T2	24	0.0	NA	NA	20	0.0	NA	NA	4	0.0	NA	NA
T3 (strongest)	22	0.0	1.00	Ref	11	0.0	1.00	Ref	11	0.0	1.00	Ref
Knee Flexor (Hamstring) Strength												
T1 (weakest)	23	13.0	NA	NA	17	11.8	NA	NA	6	16.7	NA	NA
T2	23	0.0	NA	NA	19	0.0	NA	NA	4	0.0	NA	NA
T3 (strongest)	22	0.0	1.00	Ref	11	0.0	1.00	Ref	11	0.0	1.0	Ref

N, Number of runners at risk for AKP; OR, Odds Ratio; CI, Confidence interval; T1, weakest tertile; T2, middle tertile; T3, strongest tertile; NA, Non-applicable

DISCUSSION

The primary purpose of this study was to examine whether hip and knee strength were associated with AKP and shin injury among high school cross country runners. While the findings of this current study support the hypothesis that runners with stronger hip abductor, knee extensor and flexor muscle strength had a lower incidence of AKP injury, the results did not support the same hypothesis for shin injury.

In this study, high school cross country runners with weaker hip abductor, knee extensor and knee flexor strength values had a higher incidence of AKP. The findings are consistent with those reported by Ramskov et al in recreational runners, who found runners with higher values for eccentric hip abduction strength had a lower incidence of AKP.[20] Finnoff et al[28] also found a similar incidence (5.1%) of AKP among high school runners. In contrast to the findings of the current study, they found that runners with higher baseline hip abduction strength values were at a five-fold risk of developing AKP.[28] This finding was contrary to what was expected. The higher strength values observed may have been an adaptation to increased hip adduction moments in the injured group during early and mid-stance phases of gait due to their higher weights relative to the uninjured group.[28] As few studies have prospectively evaluated the relationship between hip abductor muscle strength and AKP, further studies are needed to help determine whether greater strength serves as a risk factor or a protective role in high school runners.

With respect to the overall sample in this study, runners with the weakest knee extensor and flexor muscle strength values were not at a significantly higher risk of shin injury than those with strongest knee extensor and flexor muscle strength values. In fact, runners with knee extensor strength values in the middle tertile had the lowest injury incidence of shin injury. While these results were contrary to what was expected, when sex-specific distributions were examined, girls with knee extensor muscle strength values in the weakest tertile indeed had the highest incidence of shin injury. This was not true for boy runners. The reasons for this sex-

Table 4. *Relationships Between Selected Lower Extremity Muscle Group Strength and Shin Injury*

	Total (N=68)				Girls (N=47)				Boys (N=21)			
	N at risk	% injured	OR	(95% CI)	N at risk	% injured	OR	(95% CI)	N at risk	% injured	OR	(95% CI)
Hip Abductor Strength												
T1 (weakest)	23	26.1	2.35	0.5-10.9	14	7.1	1.23	0.7-21.6	9	55.6	1.25	0.2-9.9
T2	22	18.2	1.48	0.3-7.5	16	12.5	2.28	0.2-28.0	6	33.3	1.00	NA
T3 (strongest)	23	13.0	1.00	Ref	17	5.9	1.00	Ref	6	33.3	1.00	Ref
Knee Extensor (Quadriceps) Strength												
T1 (weakest)	22	31.8	1.24	0.3-4.5	16	25.0	NA	NA	6	50.0	0.83	0.1-6.1
T2	24	0.0	NA	NA	20	0.0	NA	NA	4	0.0	NA	NA
T3 (strongest)	22	27.3	1.00	Ref	11	0.0	1.00	Ref	11	54.5	1.00	Ref
Knee Flexor (Hamstring) Strength												
T1 (weakest)	23	21.7	0.74	0.2-2.9	17	11.8	1.33	0.1-16.7	6	50.0	1.20	0.2-8.8
T2	23	8.7	0.25	0.1-1.4	19	5.3	0.55	0.1-9.9	4	25.0	0.40	0.1-5.2
T3 (strongest)	22	27.3	1.00	Ref	11	9.1	1.00	Ref	11	45.5	1.00	Ref

N, Number of runners at risk for shin injury; OR, Odds Ratio; CI, Confidence interval; T1, weakest tertile; T2, middle tertile; T3, strongest tertile; NA, Non-applicable

specific difference, or for why no relationship exists between knee flexor muscle strength, is not known and future study is recommended.

There was no significant relationship between hip abductor strength and shin injury. This is in contrast to Verrelst et al who prospectively observed that increased isometric hip abduction strength was protective for exertional medial tibial pain in female physical education students.[25] This relationship could be sex-specific; the lack of association between hip strength and shin injury in the present study may be related to the boys having a higher distribution of incidence of shin injury in the weakest tertile than girls comparatively to those in the tertile with the strongest muscle values.

Bennell et al reported that greater muscle mass was protective for stress fractures injuries in elite club track and field athletes.[23] Corrected calf girths and lower limb lean mass were positively correlated with tibial and fibular bone density suggesting strength may provide defense for bone injuries in runners.[38] However, their study focused on stress fractures while our injury definition included all shin injury types.

A strength of this study is the prospective design which allowed assessment of strength values prior to injury occurrence. This minimized the risk of measurement and recall bias.[3,39] Further, the prospective design provided the opportunity to appropriately determine whether the strength values were a causative rather than resultant factor.

Limitations of this study include a small sample size and a limited number of AKP cases. While information on body mass index and history of prior running injury was collected on participants, adjustments for the possible effects of these potential confounding variables could not be appropriately evaluated due to the small sample size. The associations found between hip and knee strength and AKP occurrence were significant but with few runners experiencing AKP, the associations may be partially due to Type II error. However, the fact that all injuries were in those with muscle strength in the weakest tertile provided some additional confidence in the current findings. Another potential limitation was that the strength measurements were assessed isometrically using a handheld dynamometer. Considering that running

requires concentric and eccentric muscle contractions, the construct validity of isometric strength as it pertains to running has been fairly questioned.[26,40] Messier et al reported strength values were similar among recreational runners ages 16-50 with and without PFPS, but the runners with PFPS tended to have increased knee flexor and decreased knee extensor endurance bilaterally measured with an isokinetic dynamometer compared with controls despite unilateral symptoms.[41] Lastly, as this study only included runners from one high school, the generalizability is limited to other high school runners competing across the U.S.

CONCLUSION

In summary, high school runners who developed AKP during the cross country season had weaker muscle strength values for hip abductors, knee extensors and flexors. No significant relationships between hip and knee strength values and shin injury occurrence were detected. Local muscle strength is a modifiable risk factor and based on this sample, improving hip and knee strength may reduce the likelihood of developing AKP. Future studies with larger samples sizes are warranted to assess whether interventions to improve hip and knee strength reduce the incidence of AKP and shin injury in runners.

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